GLAST Large Area Telescope
Calorimeter Subsystem

6.1 Mechanical Design and Analysis

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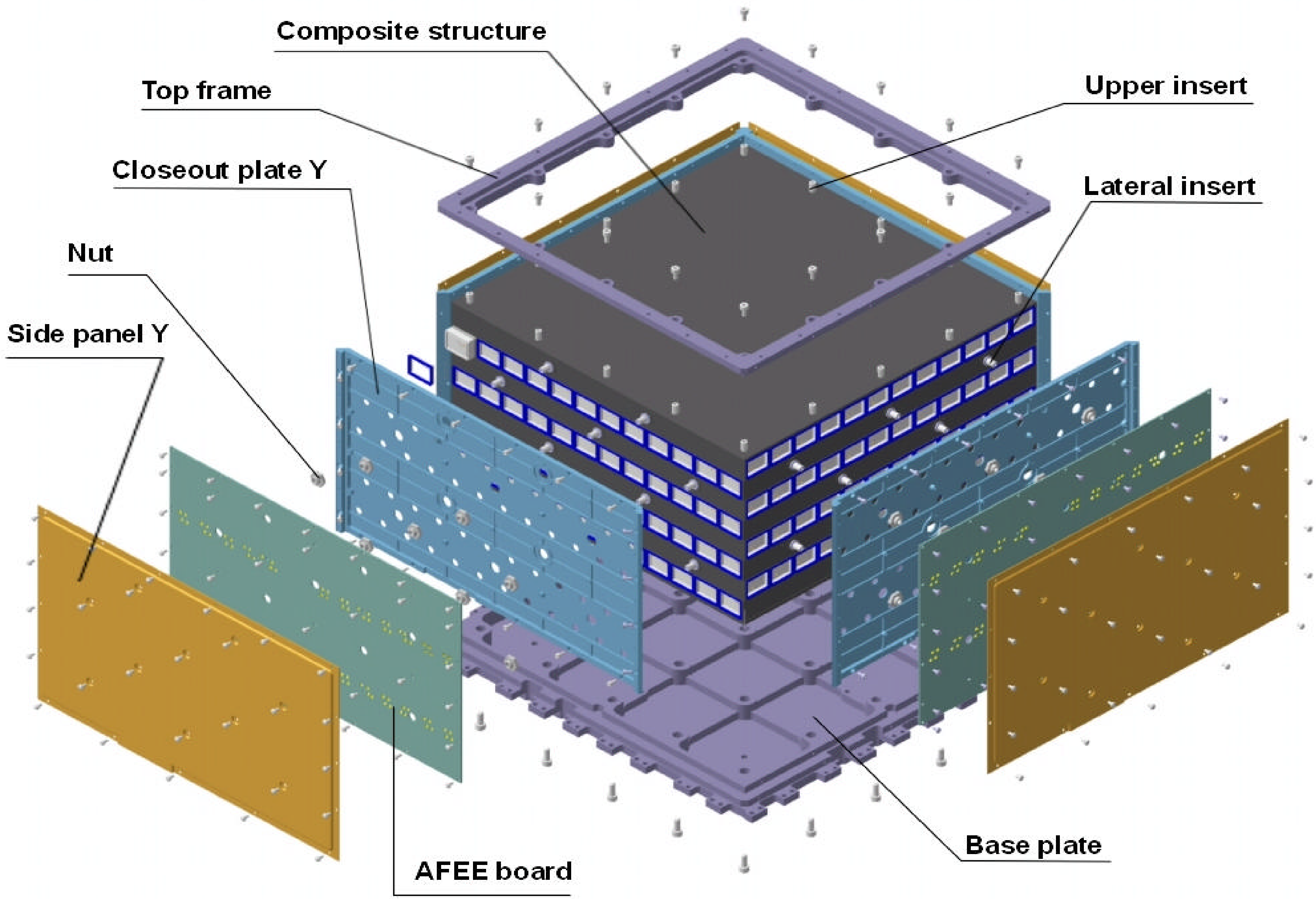
Mechanical Design & Analysis

- **Mechanical Design & Development**
  - Design Drivers
  - Description of the Mechanical Design
    - Description of the Main Components of the Mechanical Structure
    - Interfaces Between the Components
  - Development of the Mechanical Design
    - Prototypes and Models
    - Tests and Results
- **Structural Analysis**
  - FEA Modeling
  - Analysis & Results
- **Summary**

Design Drivers

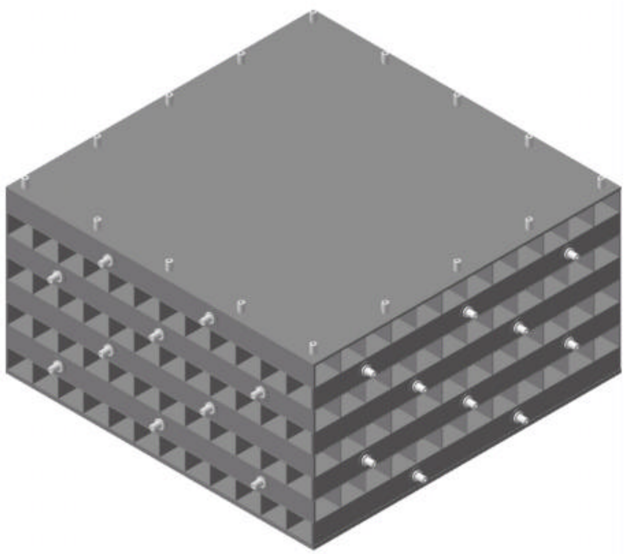
- **Structure Strength**
  - Design Structure Able to Carry 78 kg of CsI Crystal Under Environmental Loads
  - Provide Safe Housing for Fragile CsI Crystals Logs
  - Avoid Relying on Crystal Mechanical Properties to Ensure Structural Stiffness of the Cal Modules.
- **Structure Dimensions**
  - Minimize Gaps Between Crystal
  - Avoid Cumulative Effect of CsI Log Tolerances on Final Dimensions of the Cal Modules
- **Interfaces**
  - Solve Dilemma: Allow Thermal Expansion of CsI Logs (High CTE) Yet Secure Them Under Launch Loads
  - Accommodate Room and Provide Support for AFEE Boards With Efficient Shielding and Yet Minimize Gaps Between Module

PEM Mechanical Design



Design Concept – Composite structure

- One Stiff, Dimensionally Precise Composite Structure With Individual Cells for the CsI Logs (96 Cells Per Module)
- Titanium Inserts on the Sides to Allow Attachment of the Mechanical Parts
  - The Composite Structure Carries the Loads
  - It Defines the Overall Dimensions of the Cal Module
  - Each CDE Is Independent

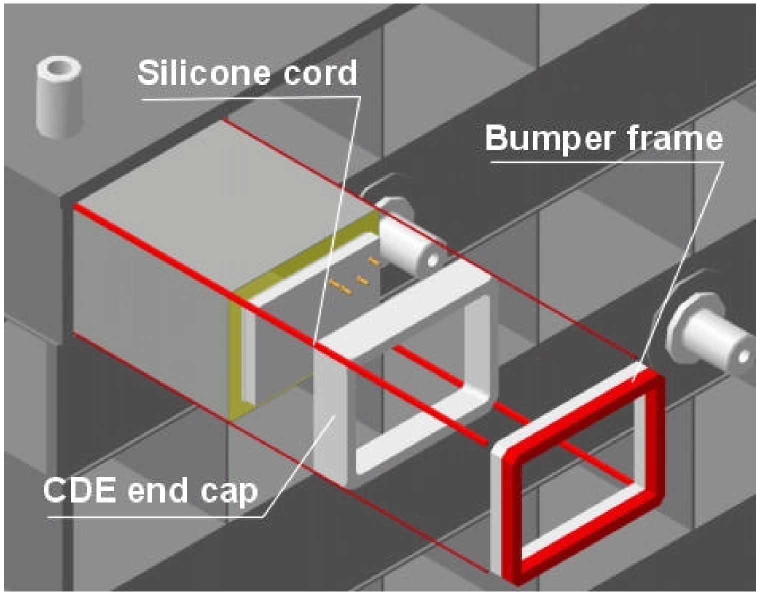


Composite Structure
HS T300 1K Carbon Fibers
M76 Epoxy Resin

Structure dimensions	Nominal (mm)	Tolerance (mm)
Transverse dimension	337.0	±0.2
Total height	176.8	±0.2
Cell width	27.35	±0.05
Cell height	20.50	±0.05
Vertical wall thickness	0.36	±0.05
Horizontal wall thickness	0.84	±0.05
Top wall thickness	2.04	±0.1
Lateral wall thickness	2.04	±0.1
Base wall thickness	4.08	±0.1

Design Concept – Interface With CDEs

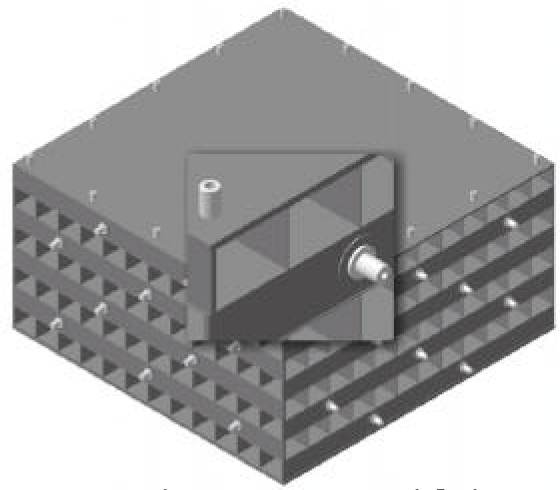
- **Elastomeric Parts to Interface the CDEs with the Mechanical Structure**
  - **Silicone Cords Placed Along the Chamfers of the Crystals Center the Logs Inside the Cells and Ensure Their Transverse Support**
  - **A Bumper Frame Placed Between the End of the CDEs and the Closeout Plate Ensures the Longitudinal Stop (Soft Silicone and Rigid Plastic Frame)**



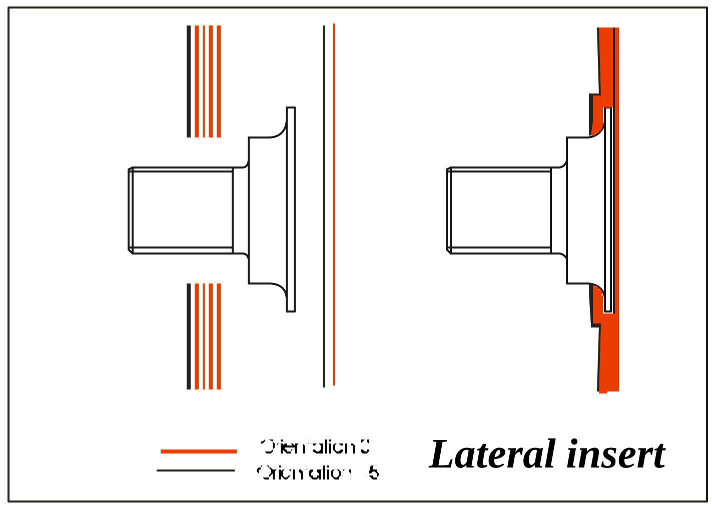
- **Tension of the Silicone Cords Reduces Their Diameter and Provide Room for the Insertion of the CDEs: 200% to Reduce Diameter from 1 mm to 0.7 mm**
- **Compression of the Cords: 0.1mm per 100N Ensure Efficient Support of the CDEs Under Launch Loads**
- **Preload of the Bumper Frames Provide CDE Longitudinal Stop Independently of the Crystal Length**
- **Max Preload 30N Keeps Stress on the CsI Material within Acceptable Level**

Design Concept – Attachment of Parts

- **Custom Titanium Inserts on the 6 Sides of the Composite Structure**
  - **They Provide the Attachment for All the Aluminum Parts**
  - **The Base Inserts Carry the Loads from the Cal Module to the Base Plate**
  - **The Lateral Inserts Carry the Loads From Transverse Accelerations or Expansion of the CDEs**
  - **All the Inserts Carry the Load Resulting From the CTE Mismatch between the Composite Structure and the Aluminum Parts**
- **The Inserts are Embedded in the Composite During the Lay-Up of the Pre-Preg and Co-cured with the Structure**

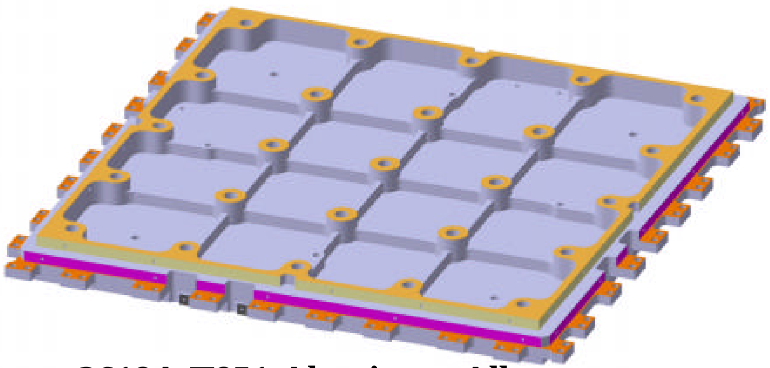


Composite structure with inserts



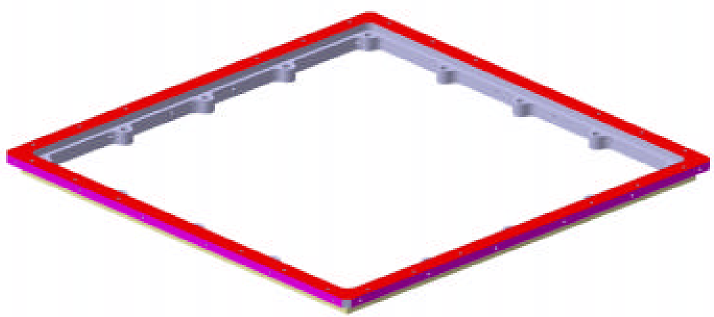
Lateral insert

Design Concept – Aluminum Shell



- 2618A T851 Aluminum Alloy
- Total Mass 3.19 Kg
- Helical Coils in All the Threads

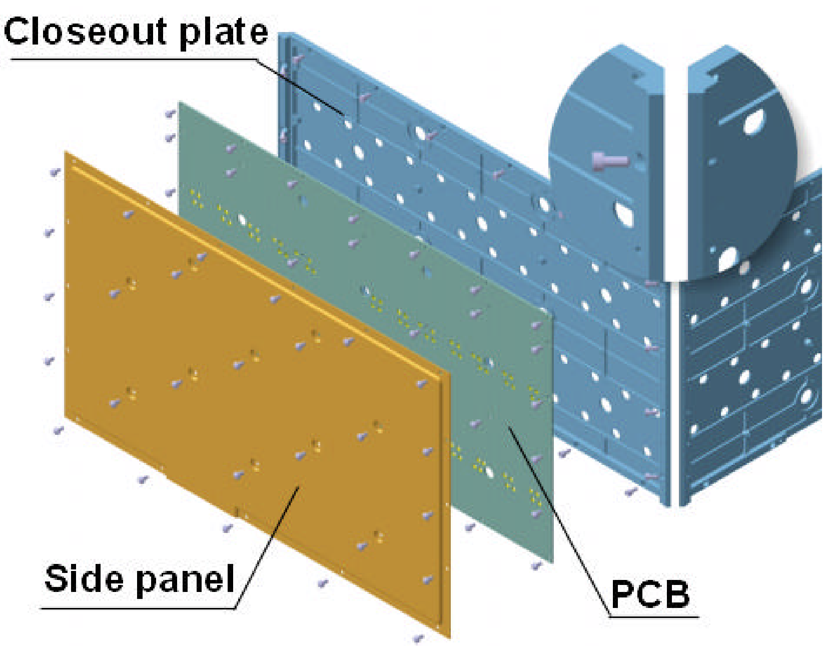
- The Base Plate Interfaces the CAL Module With the Grid through the 36 Tabs on Its Perimeter. The Friction Joint Contributes to the Stiffness of the Grid by Closing its Bays. The Plate is Attached to the Titanium Alloy Inserts Embedded in the Base of the Composite Structure.



- 2618A T851 Aluminum Alloy
- Total Mass 0.63 Kg

- The Top Frame is Mounted on the Top of the Composite Structure. It Allows the Attachment of the Side Plates but also Provides Material to Connect the Lifting Fixture on the CAL Module.

Design Concept – Aluminum Shell



- 2618A T851 Aluminum Alloy
- Close-Out Plate Mass: 0.33 Kg
- Side Panel Mass: 0.15 Kg
- Helical Coils in All the Threads
- Corners of Close-Out Plates Fastened Together to Improve Stiffness

- **The Closeout Plates Close the Cells, Preloading the Bumper Frame. They Also Provide the Support and EMI Shield for the AFEE Boards. They are Attached to the Lateral Inserts of the Composite Structure, Base Plate and Top Frame, Improving the Shear Strength of the CAL Modules.**

- **The Side Panels are Thin Aluminum Plates that Close the Cal Module to Protect the Electronic Boards and Provide EMI Shielding. They Are Attached to the Lateral Inserts and the Other Aluminum Parts.**

Development – Design Concept

- Verification of the Concept: Main Prototypes and Models

	Description	Test	Results
	3 cell structure •2 dummy logs •1 CsI log	•Vibration test •Qual. level	• Verification of carbon cell concept
VM1	96 cell structure, Aluminum shell •93 dummy logs •3 bare CsI logs	•Vibration test •Sine sweep •Random Qual. •Sine burst Qual. •CsI logs light yield measurement	• Verification of composite structure fabrication • Verification of structure strength • Verification of CsI logs – cell interface concept

Development – Design Verification

❑ Models for the Verification of the Design

	Description	Test	Results
LM	1 layer structure •12 CDEs	• Vibration test •Random Qual. • Thermal Vacuum test •Qual. level -30°C / +50°C • CDE Light yield measurements	• Verification of CDE concept • Verification of interface between CDE and cell
VM2	96 cell structure, Aluminum shell Similar design as EM •87 dummy logs •9 CDEs	• Vibration test •Sine sweep •Random Qual +3 dB •Sine burst Qual x 1.2 • Thermal cycling (no CDEs) •16 cycles –45°C to +65°C • Light yield measurement on CDEs	• Verification of structure strength • Verification of CsI logs – cell interface concept • Verification of EM design

Development – LM

❑ LM Test Sequence

Test Report: LAT-TD-00850-02

Functional Test
Light yield on 12 CDEs

→ **Vibration Test**
Random, qual level

→ **Functional Test**
Light yield on 12 CDEs

→ **Thermal Vacuum Test**
8 cycles –30°C/+50°C
10°C/hour

→ **Functional Test**
Light yield on 12 CDEs

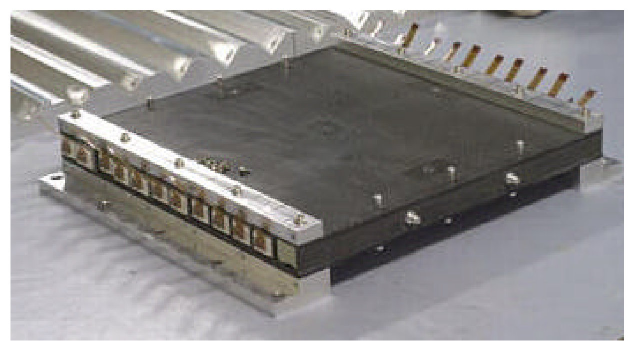
→ **Thermal Vacuum Test**
8 cycles –30°C/+50°C
10°C/hour

→ **Functional Test**
Light yield on 12 CDEs

→ **Vibration Test**
Random, qual level

→ **Functional Test**
Light yield on 12 CDEs

→ **Assembly of 9 CDEs**
Inside VM2 model

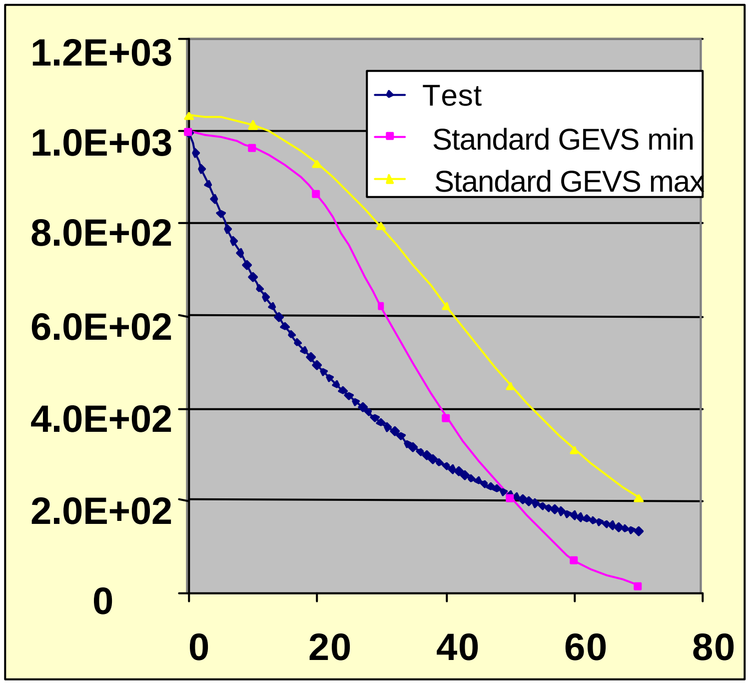


LM Model with the CDEs in Place

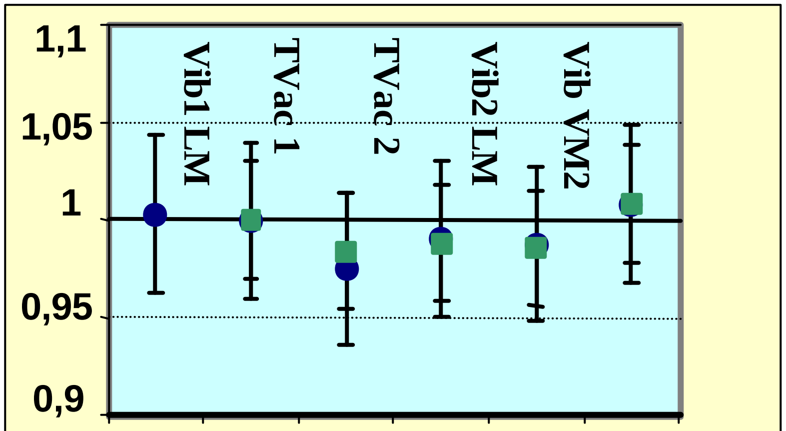
Development – LM

- LM Has Been Developed to Verify the Design of the CDEs and Monitor the Change in Performance Throughout the Entire Set of Environmental Tests
- LM Has Been Fabricated as a One Layer Only Model for Compatibility With the CEA Cosmic Test Bench

Pressure Profile - LM Thermal Vacuum Test



Light Yield Measurements



Change in light yield the for VM2/LM CDEs

Light Measurement Test Report:
CEA - SEDI-GLAST-N5600-183

Development – VM2

VM2 Test Sequence

Test Report: LAT-TD-00850-02

Inspection
Visual and Metrology

→

Thermal Test
14 cycles –45°C/+85°C
Atmospheric Pressure

→

Inspection
Visual

→

Vibration Test
Modal Survey
Random, Sine Burst
3-Axis, Design Levels
9 CDEs from LM

→

Inspection
Visual

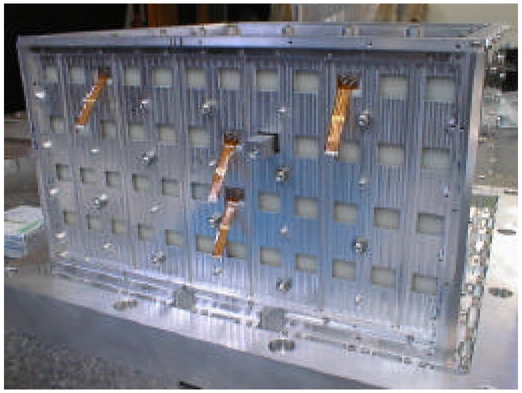
→

Thermal Test
29 cycles –45°C/+85°C
Atmospheric Pressure
(Strain Measurements)

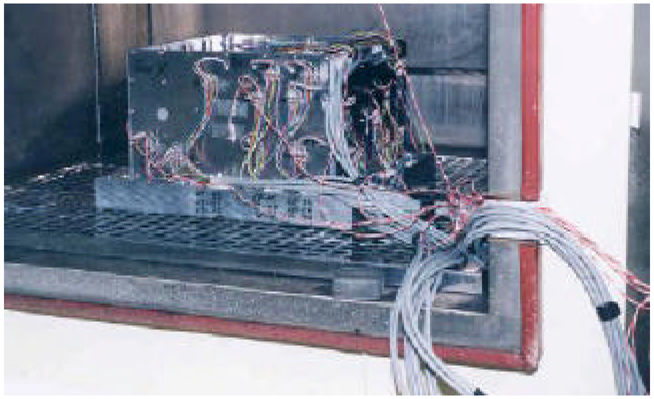
→

Inspection
Visual and Metrology

Size of Dummy Logs and +85°C to get Equivalent Load as +60°C with CsI Logs (Higher CTE)



Assembly of VM2 for Vibration Test



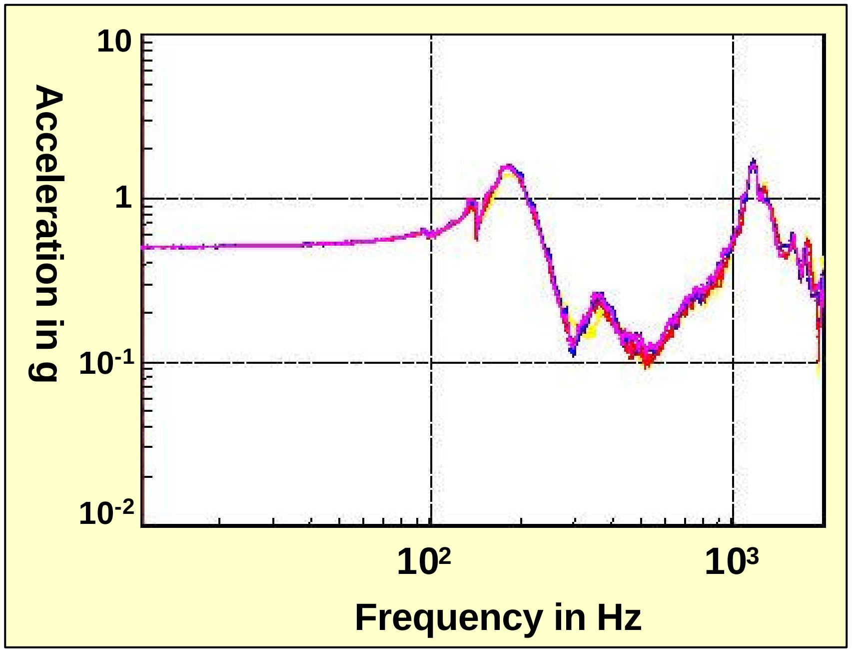
Thermal Test of VM2

Development – VM2 Vibration test

Frequency Hz	ASD LEVELS (g^2/Hz)	
	VM2 Levels	Qualification
20	0.012	0.010
50	0.005	0.041
800	0.005	0.041
2000	0.012	0.010
Overall	8.2 gRMS	7.5 gRMS

VM2 RANDOM VIBRATION TEST	
Accelerometer Position	Displacement (mm RMS)
1 – Dummy Log 2 - 6	0,269
2 - CDE 4-7	0,277
3 - Dummy Log 3-8	0,266
4 -Close-Out Plate 1	0,257
6 - Dummy Circuit Board	0,251
7 - X Side Panel Center	0,250
8 - X Side Panel Top	0,240
9 - Y Side Panel Center	0,234

X-Axis Sine Sweep / CDE in Cell 1-3
Evolution of the Signature



Fundamental Frequencies

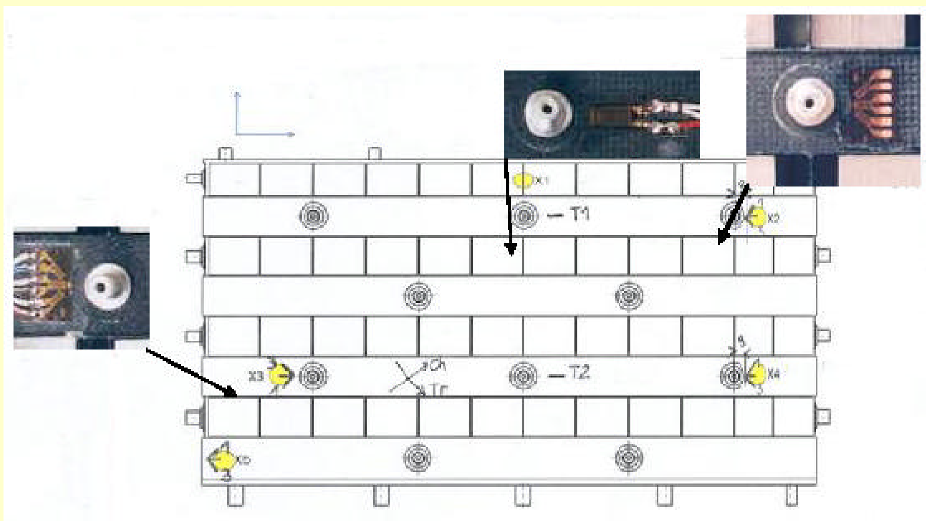
X and Y Axis: 180 Hz

Z Axis: 220 Hz

Vibration Test Report: SOPEMEA - LD31572

Development – VM2 Thermal Test

- VM2 Model Has Gone Through 43 Thermal Cycles Between –45°C to +85°C, at Atmospheric Pressure (16h per Cycle)
  - Aluminum Logs Have Been Used Instead of CsI. The Max Temperature Has Been Increased to 85°C to Compensate for the Lower CTE
- Strain Measurements Have Been Made on the Composite Structure During 9 Cycles: 13 Points on the Top and Sides of the Structure
  - The Strain Levels Have Not Changed During the Thermal Cycles



Strain Measurements on VM2 during thermal tests

STRESS MEASUREMENTS	
Position	**Stress in MPa**
Top face of structure	50
Vertical cell wall	20
Insert X side	33
Insert Y side	34

Test report: BUREAU VERITAS - NT 049/VLM/LPA

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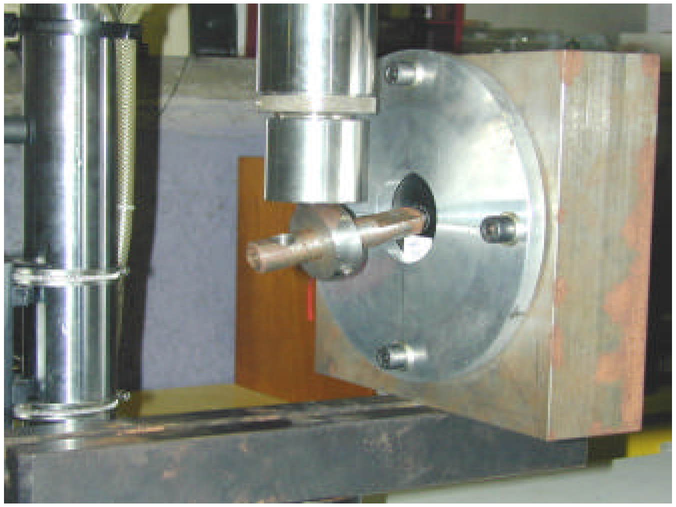
Development – Verification of the Inserts

- The Design of the Inserts Has Been Verified by Test and Analysis
- Test Coupons
  - Base, Top and Lateral Inserts Embedded in 80 mm² Composite Plates, Same Material and Lay-up as Composite Structure, Same Cure Procedure as EM (Oven 135°C)
- Test
  - Pull Test, Bending and Torsion: Min 5 Coupons per Insert Type and per Test Type
  - Pull Test and Bending Test on Lateral Inserts After 50 Thermal Cycles, -40°C to +60°C, With RH 80%

Pull Test



Bending Test

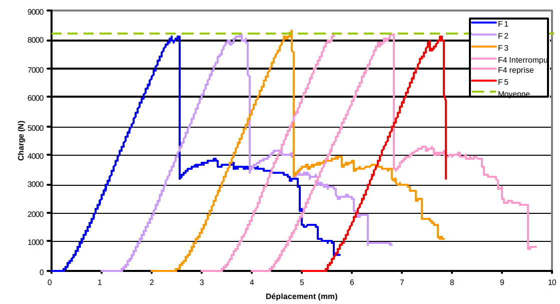
Torsion Test

Development – Verification of the Inserts

Pull Test	Base	Top	Lateral	Lateral Thermal
Failure Load (N)	8142	2076	1852	1839
Deviation (N)	159	58	48	52
Failure Mode	Composite Material Around the Inserts			

Bending Test	Base	Top	Lateral	Lateral Thermal
Failure Load (Nm)	45	11	15	15
Deviation (Nm)	2	1	0	1
Failure Mode	Composite Material Around the Inserts			

- Torsion Test: Failure Mode
  - Base and Top Inserts: Fastener (High Strength)
  - Lateral: Titanium Insert With 22 Nm Torque Value



Pull Test Results: Base Inserts

Lateral Insert Failure, Pull Test

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Development – Conclusion

- The Design of All the Critical Parameters of the CAL Mechanical Structure Ave Been Tested With Levels Higher Than Qualification
- All the Tests Have Been Successfully Passed
  - No Light Yield Evolution on the 12 CDEs Has Been Noticed
  - No Structure Failure Has Been Seen After More Than 40 Thermal Cycles With Temperature Range Greater Than Survival
  - No Structure Failure Has Been Noticed After Random Vibration and Quasi-static Loading With Levels Higher Than Qualification
  - The First Measured Natural Frequency Is Above 150 Hz
  - All Displacement Measured on Logs and Structure Are Less Than 0.3 mm Under Quasi-static Loading
  - All RMS Displacements Are Less Than 0.32 mm
  - The Inserts Have Been Intensively Tested and Show Comfortable Safety Margins to Failure

Structural Analysis – Design Requirements

- Fundamental Frequency Above 100 Hz to Avoid Any Coupling with the Grid
- Min Margin of Safety = 2, For Composite Structure.
- Max Allowed Displacement for CAL Box: 0.5 mm Under Quasi-Static Loads to Avoid Any Interference with the Grid Walls
- Max Relative Displacement Between the CDEs and Close-Out Plates: 0.3 mm to Avoid Any Contact Between the Pins of the Photodiodes and the Aluminum Plates
- Max Allowed Deflection of the PCBs: 0.25 mm Between Attachment Points

Structural Analysis – Design Limit Loads

CAL Quasi-Static Levels

	ACCELERATIONS			
	Design Lift-Off	Design MECO	Acceptance	Qualification
Lateral X,Y	2.14 g	0.2 g	6.0 g	6.8 g
Axial Z	4.43 g	6.8 g	6.8 g	8.5 g
Rotation X,Y	19.8 rad/s²	0		
Rotation Z	20.2 rad/s²	0		

CAL Random Vibration Spectra

Frequency Hz	ASD LEVELS (g²/Hz)	
	Acceptance	Qualification
20	0.005	0.010
50	0.021	0.041
800	0.021	0.041
2000	0.005	0.010
Overall	5.8 gRMS	7.5 gRMS

Structural Analysis – Design Limit Loads

- CTE Mismatch Between the Composite Material and the Aluminum Shell Induces Thermo-Mechanical Loads in the Mechanical Structure

CASE	THERMAL LOADS	
	MIN (°C)	MAX (°C)
Operating	-15	+25
Survival	-30	+50
Acceptance	-20	+40
Qualification	-30	+50

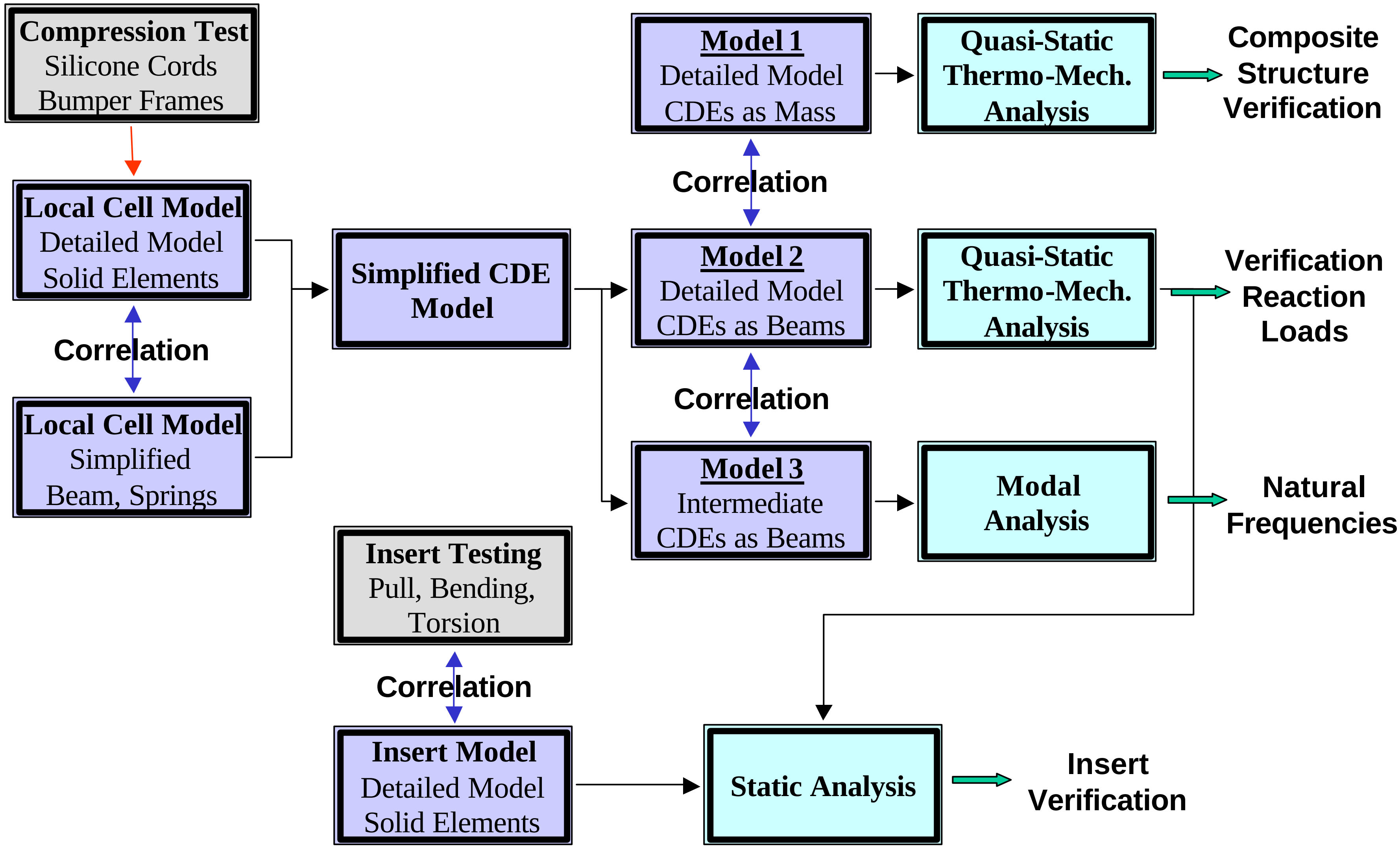
Structural Analysis – Tasks

- Levels for the Analysis are Related to VM2 Model Test Levels (20% Above Qualification) for Correlation
  - Quasi-Static Analysis
    - Individual Single-Axis Load
    - 3-Axis Simultaneous Load
  - Thermo-Mechanical Analysis
    - Temperature Reduction of 50°C (+20°C to –30°C)
    - Temperature Increase of 30°C (+20°C to +50°C)
  - Buckling Analysis
  - Modal Analysis
  - Interface Loads Analysis
    - Grid Interface Loading on CAL Tabs due to Limit Loads
    - Grid Interface Loading on CAL Tabs due to Out-of-Plane Grid Distortion
    - TEM/TPS Interface Loading on CAL Base Plate

Mechanical FEA Model Description

- The FEA Models of the CAL Module Have Been Built with SAMCEF V8.1 and V9 from SAMTECH. Different Models Have Been Developed to Better Fit the Analysis Needs. All Models are Correlated.
  - Model 1: CDEs are Modeled as Structural Mass
    - Allows the Verification of the Stiffness of the Mechanical Structure without Contribution of the Crystals
    - Not Suited for Modal Analysis Because No Coupling Between the Logs and the Structure
  - Model 2: CDEs are Modeled as Beam Elements Connected to the Composite Structure and Closeout Plates by Linear Spring Elements
    - All the Connections Between the Components Have Been Included in the Model to Have Direct Information on the Reaction Loads on the Inserts and All the Fasteners
  - Model 3: Light Version of Model 2 to Perform a Modal Analysis
  - Local Detailed Model to Simulate the CDEs Inside the Cells and the Contribution of the Elastomeric Parts
  - Local Detailed Model to Verify the Strength of the Inserts
- Additional Modeling Has Been Performed to Address Interface Aspects

Mechanical FEA Modeling



Mechanical FEA Modeling

Model 2

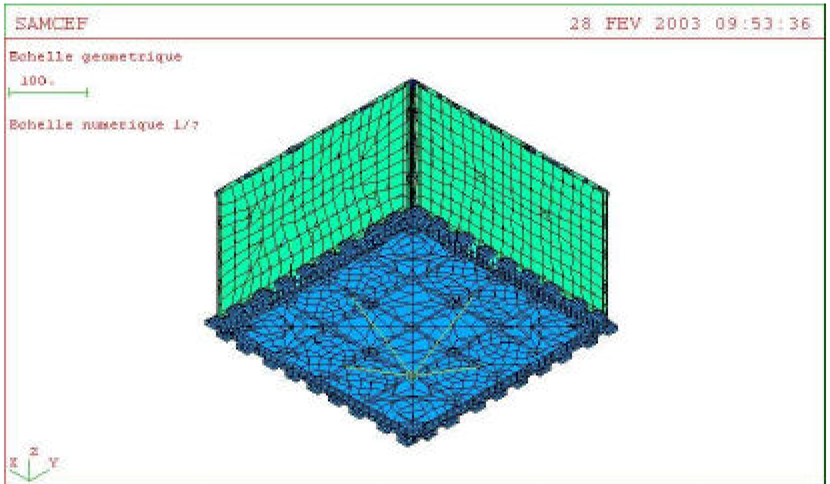
Component	Reference	Material	FE Element
Composite Structure	LAT-DS-00973	T300 1K HS Carbon M76 Epoxy Resin	Thin Laminate Shell Type 56
Base Plate	LAT-DS-00919	2618A T851 Aluminum	Solid Type 11
Top Frame	LAT-DS-00917	2618A T851 Aluminum	Solid Type 11
Close-Out Plates	LAT-DS-00920/21	2618A T851 Aluminum	Thin Shell, Beams Type 55 - 56 – 52
Side Panels	LAT-DS-00923/24	5751 H111 Aluminum	Thin Shell Type 55 – 56
Inserts	LAT-DS-00927/28/29	Ti-6Al-4V Titanium	Beam Type 52
Silicone Cords	GLAST-LLR-SP-034	7611B Silicone	Linear Spring Type 75
Bumper Frame	LAT-DS-00925	PBT - 7601B Silicone	Linear Spring Type 75
CDEs	LAT-SS-00239	Cesium Iodide	Beam Type 52
PCBs	LAT-DS-01326/27	Glass Fiber-Polyimide	Thin Shell Type 55 – 56
Electronics Box			Beam, Mass Type 52 - 159

Mechanical FEA Modeling

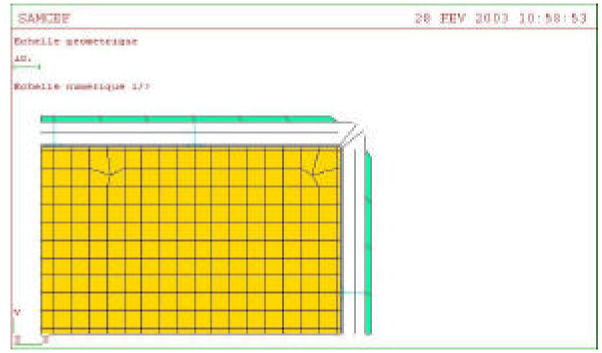
Isotropic Materials	Density Kg/m^3	Modulus MPa	Poisson's ratio	Yield Str. MPa	CTE $10^{-6}/°C$
2618A T851	2760	74000	0.33	390	22.3
5751 H111	2670	70000	0.33	100	23.8
Ti-6Al-4V	4430	105000	0.31	850	8.0
Glass - Polyimide	1700	22000	0.20	89	12.0
CsI	4510	12000	0.26	1.86	54.0

Composite	Longitudinal	Transverse	Transverse
Tensile Modulus (MPa)	101458	9126	9126
Shear Modulus (MPa)	4200	4200	4200
Tensile Strength (MPa)	1532	154	154
Compression Strength (MPa)	1452	947	947
Shear Strength (MPa)	260	130	130
Poisson's Ratio	0.3	0.3	0.3
CTE ($10^{-6}/°C$)	0.28	34.8	34.8
Density (Kg/m^3)	1310		
Values Measured on Test Coupons, Oven Cured at 135°C (Worst Case Values)			

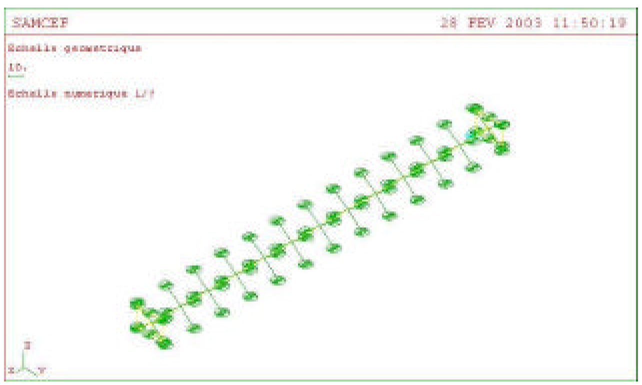
Mechanical FEA Modeling



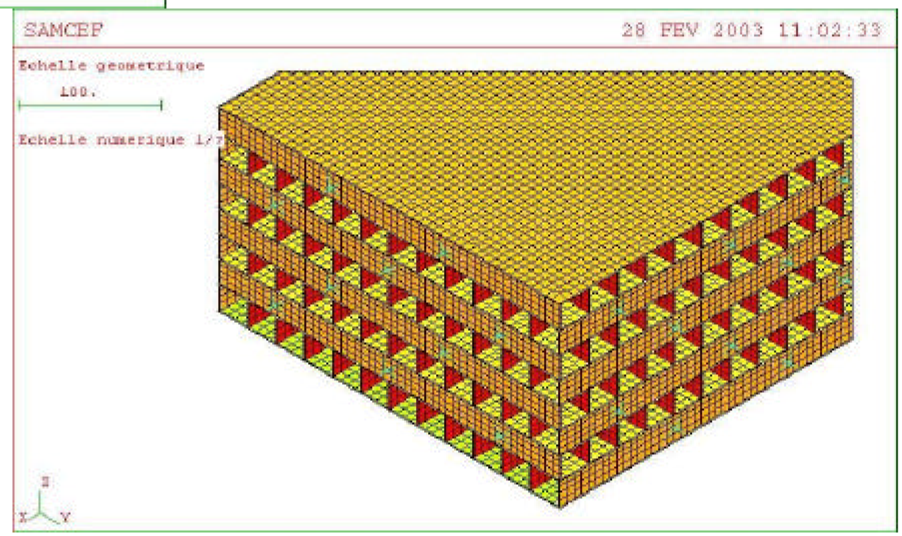
Mesh of the CAL Module



Attachment of the Aluminum Plates to the Composite Structure



CDE Beam Model with the Set of Springs that Connect it to the Cell



Mesh of the Composite with the Lateral Inserts

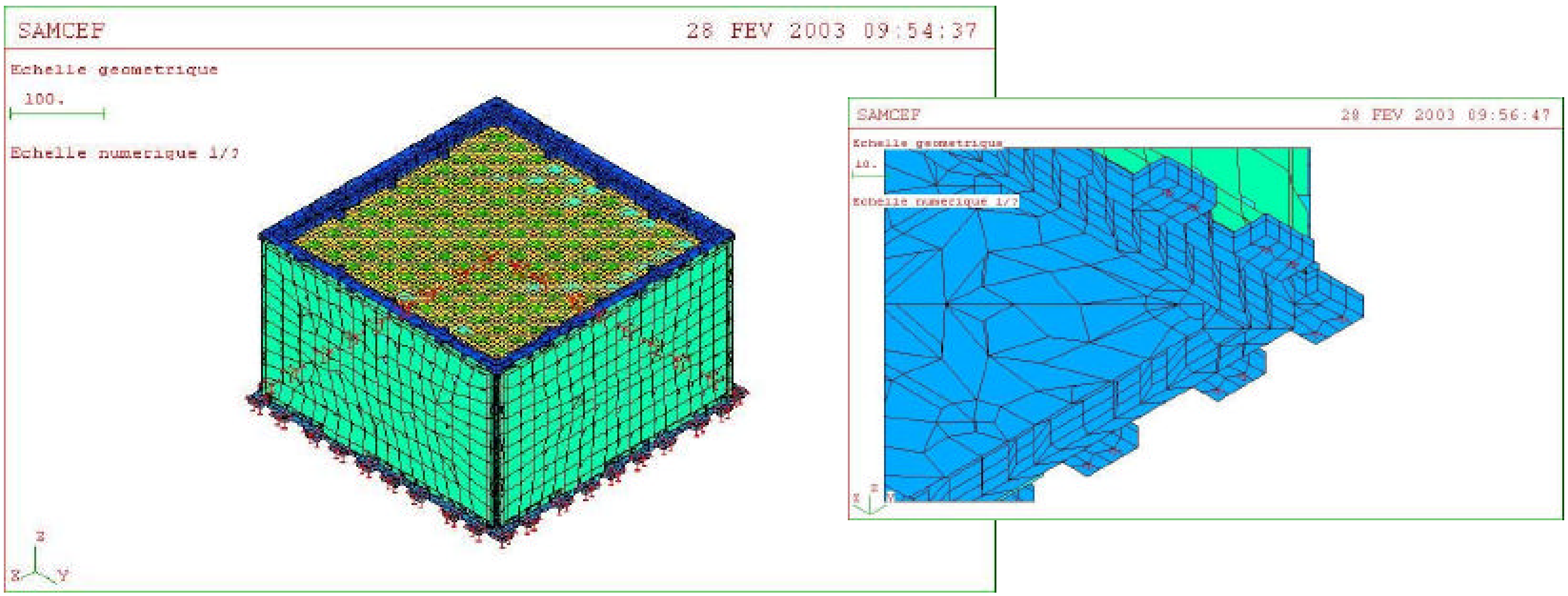
Mechanical FEA Modeling

Mass (kg)	Mass Estimate (CAD Model)	Mass FEM
Composite Structure	2.85	2.84
Base Plate	3.22	3.32
Top Frame	0.62	0.63
Close-Out Plates	1.21	1.09
Side Panels	0.63	0.63
Inserts	0.27	0.24
Silicone Cords	0.1	0
Bumper Frames	0.2	0
CDEs	76.53*	76.53
PCBs	1.44	0.70
Electronics Box	-	13.75
TOTAL	87.07 / 100.82	99.73
* All CsI Logs with Max Dimensions		

Quasi-Static Analysis Methodology

Load Case for Analysis

Load case	Boundary conditions
• 12g X Unidirectional • 12g Y Unidirectional • 12g Z Unidirectional • 7.5g X-Y, 8.5g Z Combined	TX, TY, TZ = 0 For 2 Nodes on Each Tab of the Base Plate (Fastener Positions)



Boundary Conditions: Nodes at the Same Position as the Fasteners

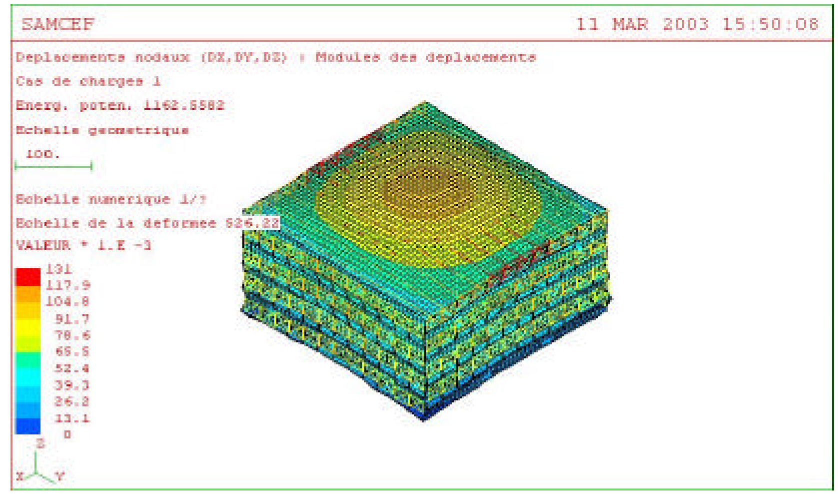
Quasi-Static Analysis Results

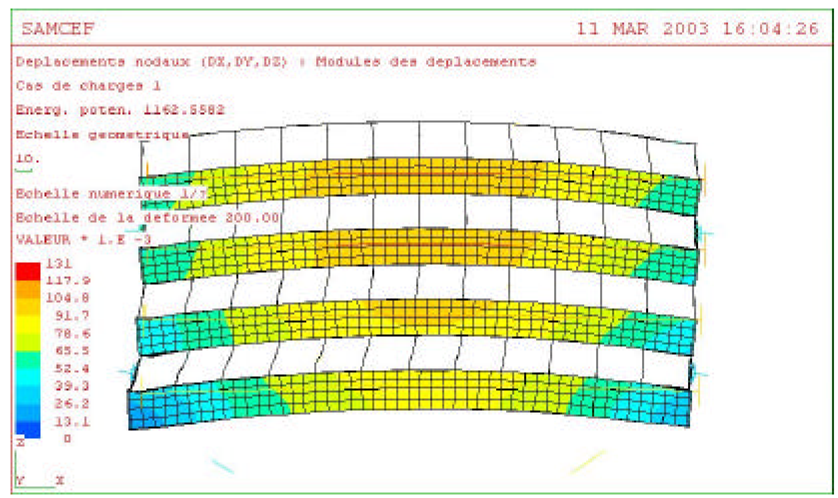
- **Results of Combined Load Case Analysis with:**
  - **7.5g Transverse X and Y**
  - **8.5g Axial Z**
- **Single-Axial Load Cases are Useful for the Correlation with the Environmental Test Results**
- **All Displacements are Less Than 0.14 mm (Max. Value for CsI Log on the Top Row.**
- **Tsai Safety Margins Are Greater Than 9.7**

Tsai Margin Indicate Load Fraction Than Can Be Further Applied Before First Ply Failure:

$$M = \frac{1}{\sqrt{TS}} - 1$$

With TS Tsai-Hill Criterion





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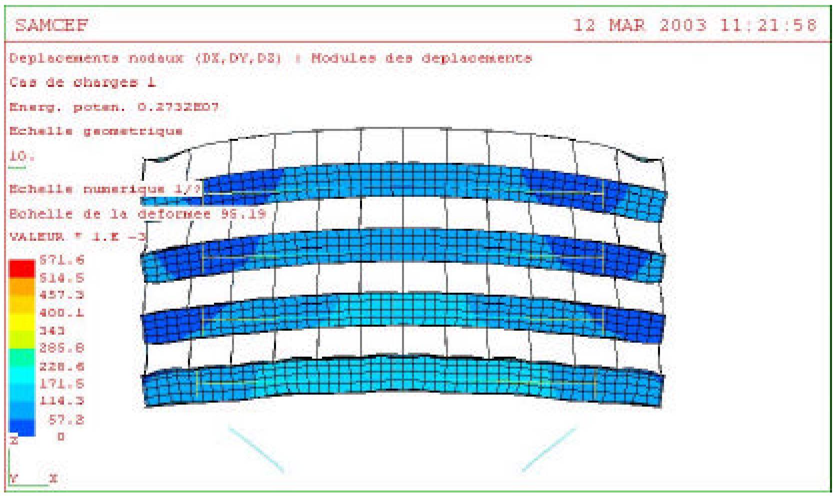
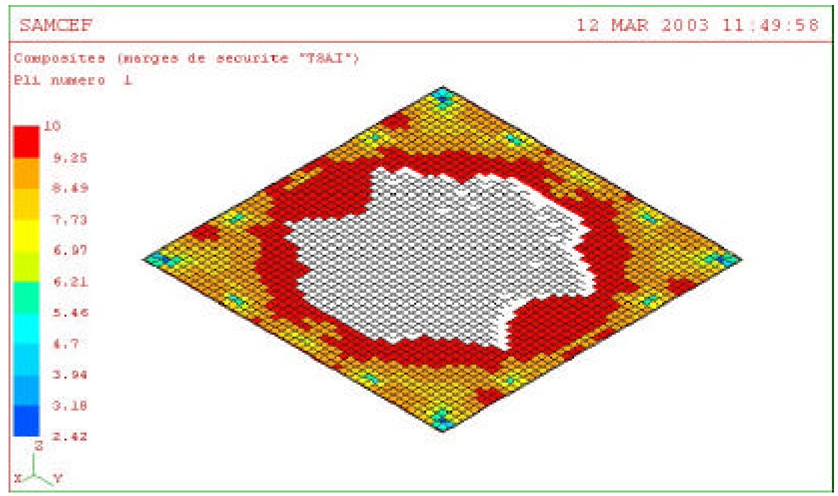
Thermo-Mechanical Analysis

Load Case for Analysis

Load case	Boundary conditions
• +30 °C Temperature Increase • -50 °C Temperature Reduction	TZ=0 For the Nodes on the Lower Face ff the Tabs TX=0 For Y Symmetry Plane TY=0 For X Symmetry Plane



Contraction of the CsI Logs Inside the Composite Cells
DT-50 °C



Tsai Margin of Safety for the Composite Structure 2.9 Min (Top of the Structure)
DT-50 °C

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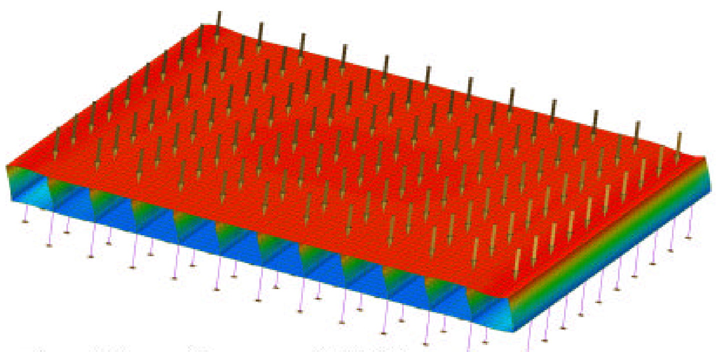
Buckling Analysis

- The Buckling of the Structure is Prevented by the Presence of the CsI Logs Inside the Cells. Still, the Composite Structure Alone Provides Enough Safety Margin
- A Local Simplified Model Has Been Developed for the Buckling Analysis of the Composite Structure. Analysis Will Be Verified on the Full Model
  - 1 Layer of 12 Cells, Model Includes Only the Composite Structure
  - Assumption of a Uniform Loading Has Been Made, Resulting From the Weight of 7 Layers of CsI Logs Under Qualification Level Accelerations
  - The Layer is Supported where X and Y Horizontal Walls Intersect
  - The Analysis is Limited to Linear Buckling, Assuming Perfect Geometry



Buckling facor: 15.76

MODES	BUCKLING FACTORS	
	Compression	Shear
1	15.8	16.5
2	21.8	-16.5

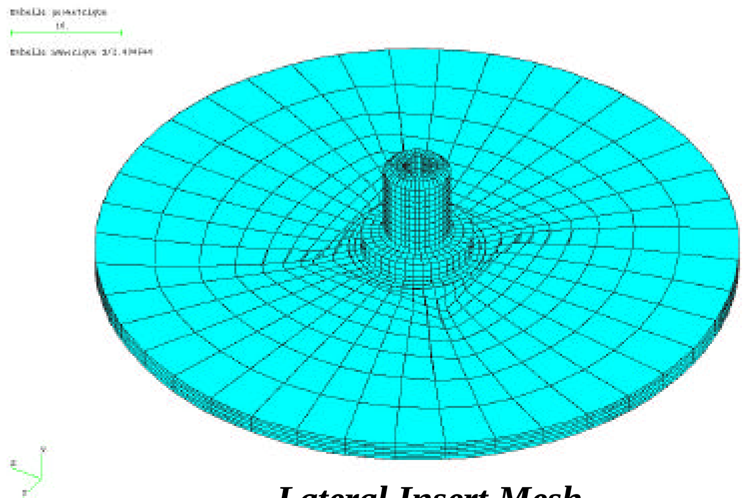
The First Buckling Mode (Compression) is Global. All the Others are Local Buckling Modes of the Inner Vertical Walls

Modal Analysis Methodology

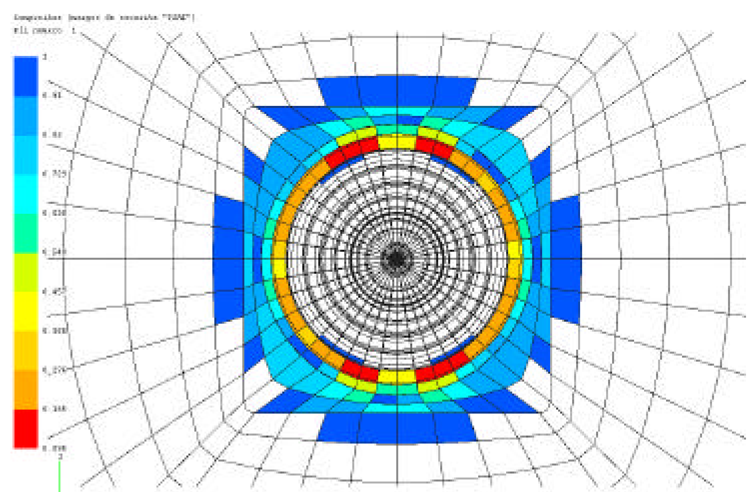
- Model 2 is Being Simplified to Reduce CPU Time Required to Complete the Analysis
  - Reduction of the Number of Nodes
  - Increase of the Mesh Size
- The Analysis Will Include Calculation of the Natural Frequencies in the 0 - 2000hz Range with Test-Like Configuration for Correlation with the EM Vibration Test Results

Insert Verification – Analysis

- FE Models of the Inserts Have Been Developed and Correlated with the Test Results
  - Solid Mesh
  - Static Linear Analysis
- Analysis Show Good Correlation with the Tests Results
  - Failure Mode is Correctly Predicted by the Models
  - Margins of Safety Always >0 With 75% of the Test Failure Load
  - Margins of Safety Always <0 With 100% of the Test Failure Load
- Testing Shows Higher Failure Loads Than Analysis



Lateral Insert Mesh



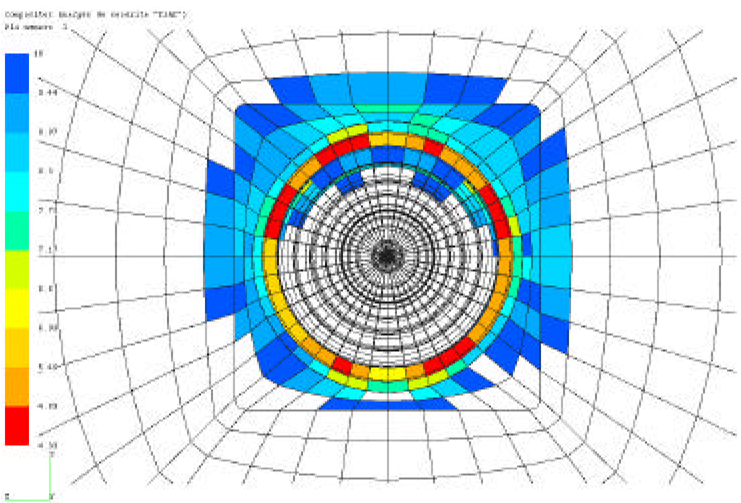
Tsai Margins at 75% of Failure Load

Insert Verification – Analysis

- The Reaction Loads on the Inserts Have Been Recovered from the CAL Structural Analysis. They Have Been Applied on the Local Model of the Lateral Inserts, which are the More Critical Ones. The Strength of the Base Inserts is Much Higher (8000N) and the Loads on the Top Inserts are Lower.

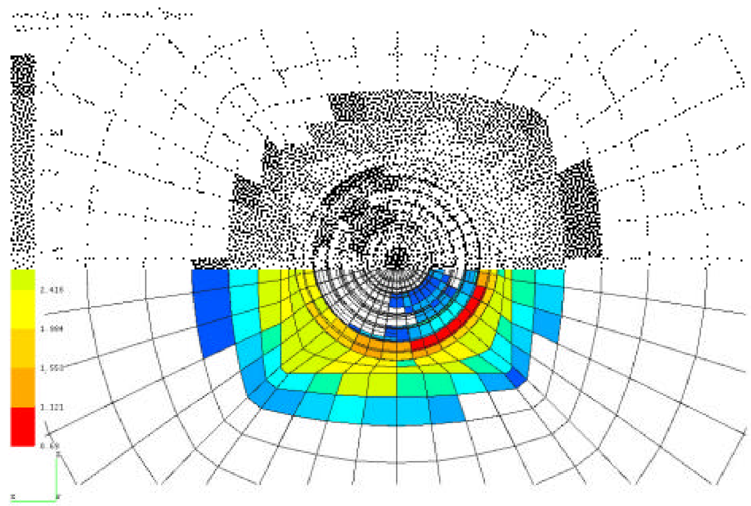
- To Reduce the Load Cases (10 Inserts Per Side, 4 Static Loads, 2 Thermal Loads), the Analysis Has Been Made for the Insert with the Max Bending Load and Max Shear Load.

Static Loads



Tsai Margins of Safety: 4.3 min
Combined Loads 7.5g X,Y – 8.5g Z

Thermal Loads



Tsai Margins of Safety: 0.69, Min
DT= 65°C (Survival 50°C)

Interface Loads Analysis Methodology and Results

- Grid Interface Loading on CAL Tabs due to Limit Loads

– Load Case for Analysis

CAL	Unit in N & m			Unit in lbs & in			
Tabs	LC1	LC2	LC3	LC1	LC2	LC3	Comments
F(x)	4373	1140	-3302	983	256	-742	Across tab in plane of plate
F(y)	206	2994	1414	46	673	318	Along tab
F(z)	-195	-11	654	-44	-3	147	Out of plane of plate
M(x)	1.39	-0.05	-6.09	12.34	-0.43	-53.85	Around x-axis
M(y)	0.45	-1.28	0.22	3.94	-11.32	1.93	Around y-axis
M(z)	20.98	4.58	-14.86	185.65	40.56	-131.49	Around z-axis

Notes: Interface loads are for CAL tab thickness of 7 mm

– Hand Calculations

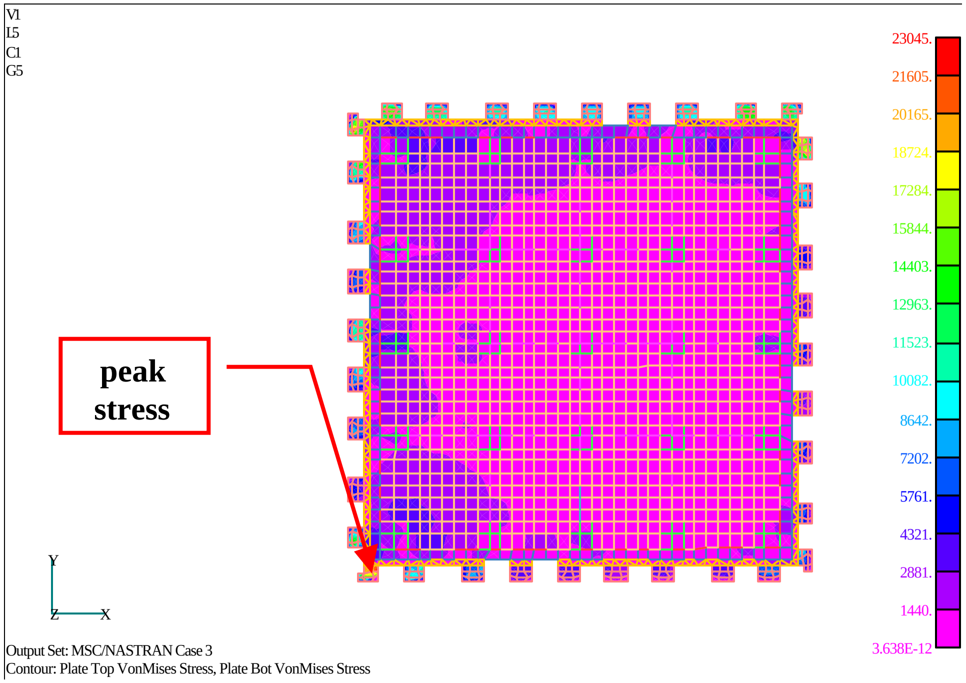
- Bending Stress, Tensile Stress and Shear Stress Calculated to Determine the Von Mises Stress
- Factor of Safety = 1.25 (Yield) and 1.40 (Ultimate)
- Margins of Safety = 0.16 (Yield) and 0.36 (Ultimate)

Interface Loads Analysis Methodology and Results

- Grid Interface Loading on CAL Tabs due to Out-of-Plane Grid Distortion
  - Load Case for Analysis
    - Interface Distortion is Superimposed with the MECO Static-Equivalent Acceleration
    - MECO Design Limit Loads and Out-of-Plane Grid Distortion Defined in LAT-SS-00778
  - FE Analysis
    - Interface Distortion and MECO Design Limit Loads are Applied to the CAL FE Model

Interface Loads Analysis Methodology and Results

- **Grid Interface Loading on CAL Tabs due to Out-of-Plane Grid Distortion - Continued**
  - **Results**
    - **Peak Stress = 23.0 ksi (at the Left Corner Tab)**
    - **Factor of Safety = 1.25 (Yield) and 1.40 (Ultimate)**
    - **Margins of Safety = 0.27 (Yield) and 0.49 (Ultimate)**



Interface Loads Analysis Methodology and Results

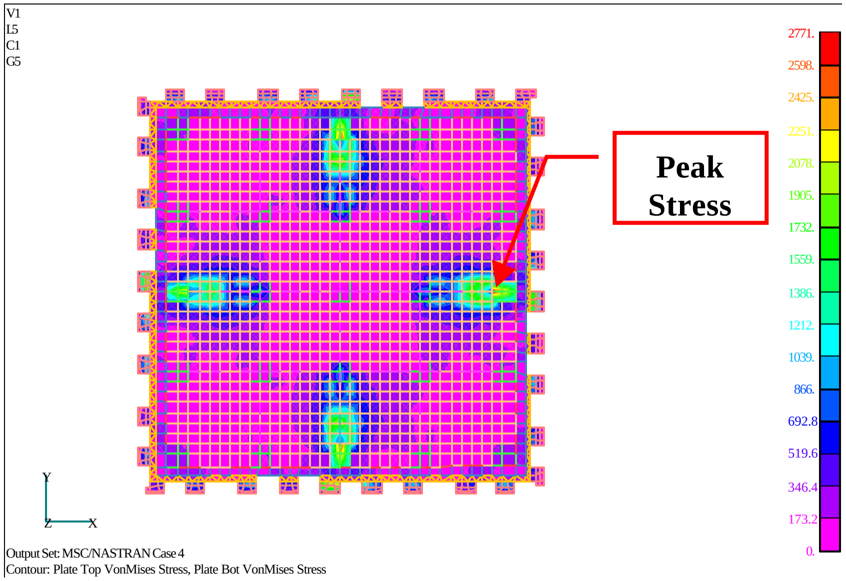
- **TEM/TPS Interface Loading on CAL Base Plate**
  - **Load Case for Analysis**

E-Box Stand-Off	Unit N-m	Unit Lb-in
Tension	3,750	844
Compression	2,625	591
Shear	1,288	290
Bending Moment	19.3	170.9

  - **FE Analysis**
    - **Interface Load Applied to the CAL FE at a Node 15 mm Below the Interface to Produce the Required Bending Moment**

Interface Loads Analysis Methodology and Results

- **TEM/TPS Interface Loading on CAL Base Plate - Continued**
  - **Results**
    - **Peak Stress = 2.8 ksi**
    - **Factor of Safety = 1.25 (Yield) and 1.40 (Ultimate)**
    - **Margins of Safety = 12.0 (Yield) and 14.0 (Ultimate)**



Analysis Results – Margins of Safety

Component	Material	Yield (MPa)	Ultim. (MPa)	M.S. (2) Static	M.S. (2) Thermal
Composite	T300 1K/M76	-	564 (2)	39.6	2.9
Base Plate	2618A T851	390	420	114.0	3.0
Top Frame	2618A T851	390	420	10.3	4.6
Close-Out Plates	2618A T851	390	420	9.7	2.4
Side Panels	5754 H111	100	220	11.2	4.7
Inserts	Ti-6Al-4V	850	1000	4.3 (3)	0.69 (4)
PCBs	Glass / Poly.	-	89	14.3	3.3
Grid Interface	2618A T851	390	420	0.27	-
TEM Interface	2618A T851	390	420	12.0	-

(1) Margins of Safety are Tsai Margin, Assuming Yield Strength for Aluminum and Titanium Alloys
(2) Values Have Been Measured on Test Samples, Weave Direction
(3) Calculated for Lateral Inserts Only
(4) Temperature Reduction of 65°C Instead of 50°C

Structural Design Status

- Design Meets Strength and Stability Requirements
  - Positive Margins Have Been Calculated for All the Components
  - Displacements Are Within Acceptable Range for All the Components
- Modal Analysis Results are Not Yet Available but Previous Tests Have Already Demonstrated a Fundamental Frequency Above 150 Hz for the CAL Module (VM2), Showing Comfortable Margin to the Requirements
- Additional Analysis on the Inserts is Required to Clearly Identify the Critical Inserts and Evaluate the Corresponding Margins of Safety
- FE Models Will Have to be Correlated with EM Test Results
- Detailed FE Model Needs to be Translated from SAMCEF to NASTRAN

Work in Progress

- Modal Analysis is Ongoing
  - Results Will Be Available After CDR
- Margins of Safety for Critical Inserts Need to Be Re-evaluated
  - LGMT, the Laboratory That Has Performed the Insert Testing and Analysis, will Provide the Results by the End of March
- Model Correlation with Test Data
  - Modeling of the Interface Between the CsI Logs and the Composite Cells is a Complex Task Because of the Highly Non-Linear Problem of the Silicone Cords. Current FE Models have been Correlated with Results from Compression Tests and VM2 Vibration Test. Because the Specification of the CsI Logs Has Changed, the FE Models Must be Correlated with EM Test Results
  - Additional Time is Necessary to Correlate Results with Test Data Following EM Structural Environment Testing

Work in Progress (cont)

- **FE Model Translation to NASTRAN for NASA-GSFC Deliverable**
  - **The CAL FE Models Have Been Developed with SAMCEF FEA Software. Because These Models Were Not Originally Created with a Translation to NASTRAN in Mind (for Required Deliverable), They were Created Using SAMCEF-Specific Design Elements and Functionalities.**
  - **Translation to NASTRAN is Requiring a Additional Effort from DDL, the Company Tasked to Provide Analysis for LLR. Additional Time is Necessary to Complete This Task.**
- **Independent Review of Analysis Needs to be Completed**